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Investigaton of the Wave Forms of Alternators and Synchronous Converters

Electrical Engineering
B. S.

1901

INVESTIGATION OF THE WAVE FORMS OF ALTERNATORS AND SYNCHRONOUS CONVERTERS.

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THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE IN

ELECTRICAL ENGINEERING

IN THE

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE, 1901.

UNIVERSITY OF ILLINOIS

May 31, 1901. 190

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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ENTITLED Investigation of the Wave Forms of Alternators and Synchronous Converters

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Electrical Engineering.

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Investigation of the Wave Forms of Alternators and Synchronous Converters.

PREFACE.

The subject of this thesis, that of wave form study, was taken up on account of the growing importance of investigation in the application of alternating currents. It forms the particular line of research of the author as a thesis in the College of engineering in the University of Illinois.

It may be said, that the field was too broad and the difficulties of the work underrated. Instead therefore of an extended study of alternator wave forms, the work became more nearly allied to the development, design and construction of apparatus for the actual investigation originally intended to be made.

The apparatus finally developed and constructed was a modification of the Blondell oscillograph for the automatic recording of current waves, using a high frequency alternating-current galvanometer, and a photographic recording device. This particular apparatus was made with great care and having very high frequency, gave excellent results.

The conclusions to be drawn may be summarized as follows: Inductance in the circuit tends to introduce peaks in the curve, distributed capacity having the effect of flattening the wave, and concentrated capacity having the effect of introducing small, sharp irregularities in the outline of the wave

form. Electrolytic capacity does not seem to follow the law for either distributed or concentrated electrostatic capacity and has more nearly the effect of an inductive reactance.

The difficulties encountered in the work were chiefly in the correct designing and careful construction of the instrument used and in obtaining the actual operating conditions desired in the use of generators and alternating-current circuits.

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0062	Manipulation, handling,- use.
0063	Functional working.
0064	Operative working.
0065	Regulation and control.- Method.
0066	Faulty working and remedies.
0069	Repairs.
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0086	Regulating and controling device.
0087	Dist. arr. Switch Board.

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Bibliography.

Annalen der Physik. January 1901.

Telephone Magazine. vol. 17 p. 5 no. 112, January 1901.

American Institute of Engineers, vol. 10 p.500.

A Laboratory Manual of Physics and Applied Electricity. E.L. Nichols, vol.2.

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Chapter I.

An Historical Review of Wave Form Investigations.

1. The study of alternating-current wave forms is a rather recent advance in electrical science, rendered necessary by the various designs of alternating current machinery, and the different kinds of circuits supplied by alternating currents. In the days when alternators were first built, no attention was paid to their wave forms, and it was generally supposed that alternating-current generators delivered sine wave forms of both current and E.M.F., and that these forms existed throughout the circuit. Later, when the subject began to be investigated, experimenters were surprised to find that most machines delivered almost anything else, rather than a sine curve of current or electro-motive force. This was at first ascribed to faulty instruments used in the experiments, but exact repetition of the same curve, and a mathematical study of the theory of the subject showed that such results were to be expected.

2. The primitive dynamo was a bi-polar machine and the lines of force from the fields were supposed to pass straight from one pole to the other in parallel lines, the field throughout being of uniform intensity. Then, if the speed of

the armature were uniform, the curves of the current and electromotive force would have the sine form, but these ideal conditions existed only in imagination. The field was not uniform in intensity, and the lines of force were not straight between the pole forces. When an armature revolves in a magnetic field the effect is to deform the field. The cutting of the lines by the conductor produces one deformation, and the field produced by the current in the armature produces another. The result is a field very far from the ideal conditions for a sine curve.

Later, when an attempt was made to make multipolar machines it was supposed that the wave would be extremely flat, and altogether unlike a sine curve, but it was found that the distribution of flux was such as to approximate very well to a sine curve.. The deformation of field did not produce such a marked deformation of wave form as in the bi-polar machine, and it was found that with a smooth-core armature, and surface windings it was possible to get a wave quite closely resembling a sine curve.

At first the delineation of the wave form of an alternator was regarded merely as an interesting experiment and only of slight scientific or engineering value. The first importance that was attached to it, was to investigate the condition of the field.

Now, however the investigation of the alternating current wave form has ceased to be a scientific experiment, of no real value, and is applied not only to machines but also to the circuit operated by them, and it is now understood that the wave forms are a very important feature of alternating current

study, affecting as they do, the operation of almost every electro-receptive device using alternating current, with the possible exceptions of the incandescent lamp and heating coils.

3. Progress in the experimental work of the investigation has advanced more rapidly than the improvements of the alternators themselves. The first device used in the work was a crude form of contact maker, described in chapter two. Now, the illuminating oscillograph enables the experimenter to do in the fraction of a second what formerly required from ten to thirty minutes. By the use of this instrument it is possible to see the actual wave form of the current or electromotive force, actually formed on a ground glass surface, and by changing the circuit or generator conditions, introducing inductance or capacity, heavy loads or light loads, to see graphically recorded, the wave forms, and to see them change with the changes in the character of the circuit.

With the old form of instrument in use, the contact maker, the results were somewhat uncertain, and unless contacts were made very closely together, it was possible to miss some point on the curve where considerable variation might occur. By the new form, the oscillograph, it is possible to note very small variations, and actually to record the ordinates of the curve at every point, and without involving any chance of error due to instrumental readings.

While the oscillograph is much quicker in operation, more certain in results, and more convenient to use, it has not yet been put to a commercial use by any of the

great manufactoring companies. The General Electric Co., still uses the contact maker and condenser described in Chapter II. Other companies use various forms of contact makers, and almost all seem to cling conservatively to the older forms of apparatus.

The oscillograph lends itself to the same set of modifications. By constructing additional galvanometers and setting them up side by side, one, two or three phase current wave forms may be traced, all adjusted to a common base line, and showing graphically the phase relations of the three phase currents. The addition of three more galvanometers of the kind adapted to it, would admit of tracing the E.M.F. curves at the same time. This, however, would involve the adjustment of six base lines all to one ordinate, which is in theory, a matter of adjustment, but in practice, a matter of difficulty.

For tracing the E.M.F. curves the galvanometer described in Chapter III and used in these investigations, is not satisfactory. The particular instrument adapted to this work, is of what is known as the Duddell type. The Duddell oscillograph is so constructed as to be entirely non- inductive and by putting it in series with a non-inductive resistance, as for instance, a pile of carbon plates, the combination may be put in shunt across the circuit while the other form of instrument is in series. By this means current and E.M.F. curves may be traced simultaneously and the records graphically obtained. Another modification of the Blondel apparatus is the series galvanometer for large currents.

The windings consist of from one to twenty turns, so arranged that any number may be in the circuit at one time, and also so that one turn may be divided. These turns are of very heavy wire and permit of very heavy currents being used. This particular instrument has not proved itself to be a very great success on account of the inductive reactance which is considerable when large currents are used. When this arrangement is used, it is necessary to set the galvanometer needle at some considerable distance from the solenoid, in order to prevent the directive-force-field for the galvanometer from crossing the field due to the alternating current.

Chapter II.

Description of Wave-form Instruments.

1. The various devices which have been used in investigating the wave form s of alternating currents may be divided into three general classes; contact-makers, curve tracers and oscillographs. While these three classes of apparatus are very different and quite sharply defined, they are not always correctly distinguished, even in text books, certain kinds of contact makers being called curve tracers, some curve tracers are called oscillographs and vice versa.

2. The contact maker is the oldest device used in this kind of work and is rather crude as compared with more modern apparatus. It consists essentially of some kind of an arrangement whereby an instantaneous electrical contact is made at different points on the alternator circuit during the revolutions of the armature. One of the earliest of these was made by mounting a wooden disc on the end of the alternator shaft, driving a metal pin into the side of the disc, and by means of a slip-ring at the base of the plate, connecting this pin electrically to one side of the alternator circuit. A movable metallic piece, usually a bit of thin copper leaf was held in such a position that at every revolution of the armature, the pin and the slip came into a momentary contact. The copper strip was connected to one side of a ballistic voltmeter, and the other side of the voltmeter to the second brush of the generator. When the copper strip, usually

called the contact brush, was held in any position in which the circuit was completed through it, the voltmeter needle would be deflected due to the E.M.F. in the circuit at the time of the contact. This voltmeter reading was considered to be equal to the E.M.F. of the armature at the instant when the contact was made. It was argued by the users of the device that if the armature was rotated with considerable rapidity, the impulse through the ballistic voltmeter would be sufficiently continuous to give a continuous deflection. The reasoning was correct, and the deflection was constant enough for all practical purposes in making observations, but it might not be absolutely certain that the voltmeter reading was really the actual voltage of the armature at the instant of the contact, especially if the readings were small.

After the E.M.F. at one point was taken, the contact brush was moved through a certain number of electrical degrees and another reading was taken. This operation was continued until a complete cycle had been covered and the curve was then plotted with E.M.F's as ordinates and electrical degrees as abscissae.

Owing to the fact that the contact made by a brush of this kind necessarily lasted for a certain definite time interval, the pin was later removed and a small metallic arc was set in the periphery of the disc. A movable brush was then allowed to rest on the circumference in such a position that the contact would be made once in each revolution. The metallic arc moving through a greater distance than the pin,

had a higher circumferential speed, and gave a shorter contact. This arrangement gave better results, but its operation was far from being perfact.

The disc being made of wood, the copper brush bearing on its surface cut the edge of the wood just between the metallic arc and the surrounding wood, covering the surface with the wood and copper cuttings, made the contact poor and the accuracy of the readings questionable. This instrument was improved by making the disc of fiber or hard rubber. The latter material served the purpose better, but after being in use some time chipped and broke at the point where the metal piece was inserted.

One of the important defects in this instrument is that the contact made by the copper brush necessarily involved a definite time interval, during which the electro-motive force of the armature might vary. If, therefore, the wave should be of a very high, peaked form, this long contact lasting through a considerable variation of the generator E.M.F. would be sufficient to introduce considerable error.

3. The contact maker of Prof. Franklin was designed to overcome this latter difficulty. He used a contact brush on a disc in much the same manner as the first described above. It was constructed with the addition of a tripping arm and finger, lifting the contact brush as soon as contact had been made. This also involved a time contact, but by varying the relative positions of the tripping arm and finger, the time of contact on the metal arc could be lengthened or shortened at will. This arrangement very materially shortened the time of

contact..

4. The perfection of contact, was, however questionable, and this led to the invention of the Bedell-Ryan contact maker[1]. The contact is made by a fine jet of water, issuing from a small nozzle, impinging upon a small pin in the face of a revolving disc, mounted on the shaft of the alternator or synchronous motor. The water head at the nozzle is about six or seven feet which is sufficient for a short jet, an unbroken stream of only two or three inches being desired. The contact is exceedingly short and practically perfect. The water is made a part of the circuit which is closed every time the needle crosses the jet. In order to prevent the needle crossing the jet twice instead of once in each revolution, the jet is set at an angle with the plane of the disc which bears the pin. The nozzle is mounted on an indexed plate, which may be revolved axially with the shaft, thus placing the jet in any desired position around the axis. In order to increase the conductivity of the jet a little sodium chloride may be added to the water. It is much better electrically, at least, than the earlier contact maker, but is cumbersome in that it invol-

[1]American Inst.Electrical Engineers,vol.10-p.500,-Bedell,Miller and Wagner.

Laboratory Manual of Physics and Applied Electricity. E.L. Nichols, vol.2 pp. 97-99.

ves the necessity of caring for the waste water, and the method is objectionable by being "wet".

5. A contact maker in use in the General Electric Co's. manufacturing plant[1] completely remedies the defect due to length of contact. It is shown diagramatically in Fig.1 The contact is made for some considerable time, during which the current is charging a condenser. The contact is then broken and quickly made on another segment on the periphery of the disc. This segment is so connected as to discharge the condenser through a ballistic voltmeter. Since the charge in a condenser is dependent on the E.M.F. at the instant the charging circuit is broken, the discharge through the voltmeter would be proportional to the generator voltage at the instant that the condenser was disconnected from the armature circuit, assuming, of course, no leakage in the condenser.

This method is not subject to the bad contacts which are a feature of the previously described instruments, but it is a question, if any method which gives a very short duration of E.M.F. in the voltmeter circuit, only about 1/1200 of the time of one revolution, even if repeated 1600 times per minute will give an E.M.F. at the voltmeter equal to the armature potential at the instant of the contact. Especially is this doubtful when the contact is being made at that part of the revolution when the potentials are low, being only a few volts.

[1]American Institute of Electrical Engineers, vol.16-p 351 C.P.Steinmetz.

6. The apparatus so far described is for electro-motive force curves only, but it may be seen that slight modifications of the circuit and contact apparatus would admit of wave-forms of currents being taken. A novel method which has been proposed, but not much used for using the contact maker for current curves, is one based on the principle of magnetic repulsion. If a fairly strong field be caused to pass across the filament of an incandescent lamp, while a direct current is passing through the filament, the filament will be deflected from its normal position, and will move away from the pole of the field and toward the other side. If the current in the lamp is alternating, the filament will vibrate to and fro, as the current changes direction. If the current from a contact maker flows through the lamp, the deflection will be in direction and quantity, proportional to the current flowing at the instant the circuit is made. By means of a mirror this deflection may be magnified ten or twelve times so that it may be readily measured. The deflection being plotted in a similar manner as E.M.F's would be in E.M.F. wave, gives the current wave. For an experiment of this kind a low voltage lamp is desirable, so that a large current should flow through the filament, producing a large deflection. This method has the advantage that when the current is small the external field may be intensified, thus a large deflection produced. Unfortunately the method is limited to low voltages, and the lamp does not last long. Inasmuch as each lamp must be calibrated, the breaking of the filament involves the calibration of a new lamp, and the

scheme is not very satisfactory. It however possesses the advantage, that when the current is small, the deflection may be greatly magnified by increasing the external field, and when it is large, may be diminished by reducing the current in the electro-magnetic windings.

7. The faults to be found in the previously described methods, led to the construction of the alternating current curve tracer. Curve tracers are of several kinds, but as they are not in very general use, it will be necessary to describe o only one, which is probably characteristic of the entire class.

This particular curve tracer was constructed by Mr. H.O. Carpenter. It is based on the principle of the telegraphone, which is described by its inventor Mr. V. Poulsen[1] and more completely by the same author in the Annalen der Physik.[2]

In the modification of Poulsen's apparatus which was used in this method, a highly tempered steel ribbon, in this particular case a clock spring, was fastened on the periphery of a wooden disc like the tire of a wheel, and fastened in its place by screws at the end. Two pieces of soft iron wire about No. 24, forming the cores and poles of an electro-magnet, were brought to the band about one fiftieth of an inch from the edge. There was an end of the wire, which end also served as

[1] Annalen der Physik,-Jan.1901 - Poulsen.

[2] Tel. Mag,- Poulsen,- vol.17,p5 No.112. Jan. 1901.

a pole piece of the electro-magnet. The magnet contained two spools, each of about forty turns of No. 26 copper wire. This

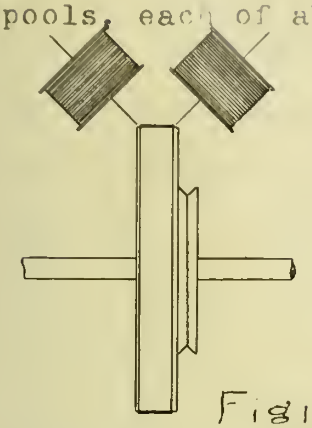


Fig 1.

part of the arrangement is shown in fig. 1 page 13 When the alternating current whose wave form was to be traced, was sent through the windings of the magnet, and alternating field was provided in the cores, varying according to the intensity of the current. The disc was then rapidly rotated, and the spring was magnetized, the field of the spring being transverse, and varying at each point in direction and intensity according to the flux in the soft iron cores, when that point of clock spring was between the pole pieces.

When the spring was magnetized the electro-magnet was removed, and a magnetometer set up immediately over it. The flux in the steel spring was directed towards the magnetometer needle by a pair of soft iron horns, embracing the spring, and turning up towards the magnetometer needle. When the disc was very slowly revolved, thus passing the spring between the pole pieces, the magnetometer needle would be deflected to the right or left, in a direction and angular amount proportional to the flux of the spring.

The needle is mounted on a fine silk fiber suspension carrying a reflecting mirror. A vertical beam of light falls on the mirror and is reflected to a horizontal drum revolving inside a light tight box. In front of the drum parallel

with the axis is a slit in the side of the box properly narrowed down in aperture by a metal plate. The reflected beam of light falls on the outside of the box in a vertical position, and crossing the slit in the box. It may thus be seen that the light falling on the drum is reduced to a very small spot. The motion of the needle and mirror causes the spot of light to move back and fourth in a direction parallel to the axis of the drum, producing the ordinates of the current wave. The rotation of the drum provides the time component, or abscisa. . The curve was traced by fastening a piece of bromide paper on the drum, and allowing the light to fall on it during the time the spot of light was moving. The bromide paper was then taken from the drum and developed in a dark room. The result was shown in a very black line.

The disc bearing the steel band was rotated quite rapidly during the process of magnetization, the peripheral speed being about 1200 ft. per minute. In the tracing of the curve with the magentometer, it was rotated about 1-1/2 feet per hour. The peripheral speed of the drum was variable but about the same speed, 1-1/2 feet per hour, was used. At these speeds of rotation, about a half hour was needed for the tracing of a curve. The rotation of the disc and drum during the tracing of a curve was accomplished by a clock work.

This method had very grave defects. In the first place it is very slow, and after one curve has been traced, the spring must be demagnetized before another wave form can be made. The complete demagnetization of a piece of highly tempered steel spring, is a slow and difficult process, and per-

fect results in this line are difficult to secure. Again it is a difficult matter to get a piece of steel band of uniform quality throughout and a variation of coercive force or of hysteretic constant is sufficient to deform the curve. The density of the magnetization in the spring must be kept low, so that only the straight portion of the magnetization curve is represented in the flux of the spring. In other words, the flux in the spring, that is the flux remaining after magnetization, must be proportional to the current producing it. If the density reached such a point that it was not proportional to the current producing it the wave form would be flattened. There was not quick method of determining whether or not this condition had been reached, and such objection is serious.

Since the magnetometer needle was acted on in a manner similar to that of a tangent galvanometer, the curve as traced was correct only when the maximum angular deflection of the needle was small.

8. The third form of apparatus used in producing wave forms is the oscillograph. This is the latest and best developed of physical instruments for the work, and it possesses many advantages. An oscillograph may be distinguished from a curve tracer by the fact that it produces its wave form at the time it is being generated by the machine, and cannot reproduce it afterwards as some of the curve tracers may be made to do.

The Blondel oscillograph consists essentially of an

alternating current galvanometer of very high frequency, that is having moving parts with a short natural period of vibration, and provided with some means of recording the vibrations in the angular deflection of the needle, as produced by the current whose wave form is to be traced.

In order to avoid eddy currents which would act indirectly on the alternating current circuits, thus deforming the wave, the galvanometer is made with no iron in the galvanometer windings, and the wire is wound on a wooden or fiber spool.

In order to secure the very high frequency of the moving parts, the needle and mirror must both be small, and should be mounted on a very long silk or quartz fiber of great delicacy. The vertical length of the mirror and needle is not of much importance, but it is essential that the horizontal distance from the axis of the suspension to the extremities of the moving parts should be extremely small.

A powerful magnetic field surrounding the needle also shortens the natural period, and by using a strong field, the frequency can be made very high. A more complete description of the Blondel type of oscillograph will be given in the next chapter.

The Duddell oscillograph is of what is sometimes called the bi-filar type, that is it has no windings, but has two fine wires mounted very closely together, bearing the reflecting mirror. Current flows down one wire and up the other. The effect is the same as an electro dynamometer in producing angular deflections. A powerful field gives directive force to a small needle.

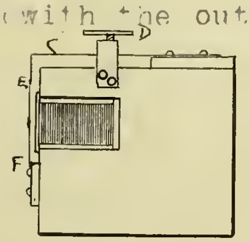
Chapter III.

Description of Apparatus Used.

Methods Pursued.

1. Instruments of the last two classes of apparatus, were used in this thesis. The curve tracer used was one constructed by Mr. H.V.Carpenter then assistant in the Physics department of the University of Illinois, and now located at the Washington Agricultural College and School of Science. It has been completely described in the preceding chapter, and further details are unnecessary. The oscillograph used was a modification of the Blondel type, and partially described in the preceding chapter. It would, however, be well to give a rather more extended description of this particular instrument.

2. The galvanometer part of the instrument consisted of a small solenoid of about sixty turns of number 25 single cotton covered soft copper magnet wire. The length of the winding was about two centimeters, and the external diameter 1.1 c.m. The winding was on a small wooden spool, mounted with its axis horizontal, in a notch cut in a block of half inch oak. The notch was of such a depth that the end of the spool was flush with the outer surface of the block. See figure 1.



The needle and mirror were mounted on a very fine silk fiber E.F. fastened at F. to a block of fiber screwed to the oaken block, and at E. to the end of a small copper spring C. which gave tension to the silk suspension. This spring which was made very weak, was regulated in position by means of the thumb screw D.

The needle was of soft Norway iron 0.009 m.m. thick .743 m.m. wide which was its horizontal length, and 3.62 m m. long. This last dimension was its vertical length. Being mounted in a vertical direction, the horizontal length on each side of the suspension was 1/2 of .743 m.m or .3715 m.m.

The reflecting mirror was made from a microscope cover glass, 0.015 m.m. in thickness. The silvering increased its thickness to 0.019 m.m. Its width or horizontal length was 0.688 m.m., thus making 0.344 m.m. length on each side of the axis of suspension. Its vertical length was 3.911 m.m.

The length and width of both needle and mirror were measured by a Geneva society dividing engine, used as a comparator, reading to one ten-thousandth of one millimeter. The thicknesses were measured by a micrometer screw guage reading to one thousandth of one millimeter.

The needle was mounted on the back of the mirror, fastened by a drop of shellac, the silk fiber being between them. The position of the suspension was made such that the distance from the needle to the outer end of the winding was about four millimeters.

Vertical length of needle	3.620	mm
Vertical length of mirror	3.911	
Horizontal length of needle	0.743	
Horizontal length of mirror	0.688	
Thickness of needle	0.009	
Thickness of mirror	0.019	

3. Directive force for the needle was provided by a magnetic field of considerable intensity. At first an electro-magnet was used, the magnet being energised by one or two cells of battery. These batteries required attention, and the field intensity changed with the changing condition of the cells. It was found that a pair of permanent steel magnets of horse-shoe form, if placed in the proper position to bring the most intense portion of their fields across the needle gave more satisfactory results. This produced a field practically constant for any desired length of time. It was quite as easily regulated as the electro-magnet field, for the needle could be moved into position bringing it into a stronger or weaker part of the field. The best results may be obtained when the galvanometer needle is in a stronger part of the field.

When an alternating current is passed through the solenoid of the galvanometer it produces deflections of the needle and mirror, in frequency, direction and amount, proportional to the current flowing, and this deflection will follow very closely any variation of the current.

4. Light from a hand feed arc lamp passing through a small slit in one side of the lamp enclosure, thence through a narrow vertical slit in a black paper hood placed over a convex lens was sharply focused on the front of the reflecting mirror. This paper slit was about three (3) centimetres long, and two (2) m.m. wide and the distance from the arc to the lens was about 2-1/8 metres. The focused image of the slit was therefore about 0.1 m.m. wide making the light falling on the mirror very intense. The ray which was reflected from the mirror passed through another convex lens to give the beam a sharp definition, and also to cut down the amplitude of vibration of the reflected ray.

The slit in the black paper hood on the lens was vertical, so that the reflected beam of light was also vertical. This ray fell on the outside of a wooden box with a horizontal slit in the side as in Mr. Carpenter's curve tracing device, and the light falling on the drum inside was reduced to a small spot. The box and drum were the same as earlier used in the curve tracer above referred to and have been described. In using it with the oscillograph, however, its speed of rotation was increased, for the curve tracer produced a curve in about a half hour, while the oscillograph produced it in one sixtieth of a second.

5. This difference in speed of tracing the wave form necessitated a faster printing sensitised paper. Bromide paper is much too slow in printing to be affected by an illumination of such short duration as would exist in tracing the curve in the sixtieth of a second, and recourse was had to

Eastman's 3-1/2" X 3-1/2" Kodak film. This had the required actinic sensitiveness and when the light from the arc lamp was made rich in violet rays, the impression made on the film was quite satisfactory. A very short arc producing what is sometimes called a "cold light" had very little effect on the film.

6. The current was brought to the room through a special pair of leads brought from the storage battery room switch board, which was also connected to a special pair of leads coming through the tunnel. A lamp bank of six lamps so arranged that any number could be put into or out of circuit at pleasure, served to limit the current to a reasonable value. This resistance was not perfectly non-inductive, but it was very nearly so, so much so, in fact, that the small amount of inductance could be neglected.

7. The method of tracing a curve is as follows: The double-pole baby knife switch is closed permitting current to flow through the lamp bank resistance and the solenoid of the galvanometer. The light of the arc lamp falls upon the convex lens and the reflecting mirror. When the deflection of the mirror follows the current, the card forming the shutter in front of the box is drawn aside and the drum rotated rapidly through a part of a revolution until the portion of the drum bearing the sensitive film has passed the slit. The card is then drawn down and the circuit in the galvanometer is broken. When the mirror has ceased vibrating, the card is again drawn back, and the drum is similarly rotated tracing the base line or line of zero potential.

8. A peculiar and interesting effect noticed in this base line, is its broken character. The arc lamp was operated by an alternating current and the alternations being of a rather low frequency, of 60 cycles per second, the effect was to break up the base line into a series of short dashes and spaces, the length varying according to the speed at which the drum was revolved. When the load on the plant transformers was heavily inductive, this effect was accentuated. When it was non-inductive it was less noticeable. Generally two and sometimes three curces were traced on a film. The film was then taken from the box, developed in a metol-hydro developer and fixed in a sodium thio-sulphate solution. They were then washed in running water for about an hour, and afterwards dried.

Another interesting feature in connection with the vibrating beam of light as it oscillated to and fro on the outside of the box, was that it was possible in many cases to judge something of the actual form of the wave before developing the film, merely by watching the intensity of the light streaks in the field of space illuminated by the vibrating beam of light.

The photographic curves were very small, only about one half to one inch in amplitude, and were enlarged by being thrown on a screen by means of a projecting lantern.

Chapter IV.

Conclusions and Deductions.

An effort was made to get curves from each machine available under the varying conditions of lag, lead and complete neutralization at both light and heavy loads. In many cases however this was not possible and in some other cases the oscilleograph was operated while the machine was working under the required conditions but the films bearing the curves were injured by fogging or by not receiving a sufficient amount of violet light which left the impression to faint to be intensified.

Owing to the fact that itwas impossible to ascertain all of the operating conditions of the machine when the curves were taken, the conclusions to be drawn must be somewhat general rather than specific. The difficulty in ascertaining all of the operating conditions lay in the fact that the plant is used for supplying power to several buildings and the laboratory. It was not always, nor even generally possible to determine exactly the conditions under which the plant was working. This makes the deductions from the curves of the plant generators and transformers uncertain in a measure, but valuable conclusions may nevertheless be drawn from a careful study.

1. Inductance in the circuit tends to produce a sharp and peaked wave. In theory, inductance would have the effect of modifying the sine wave, to the form shown in Fig. 1

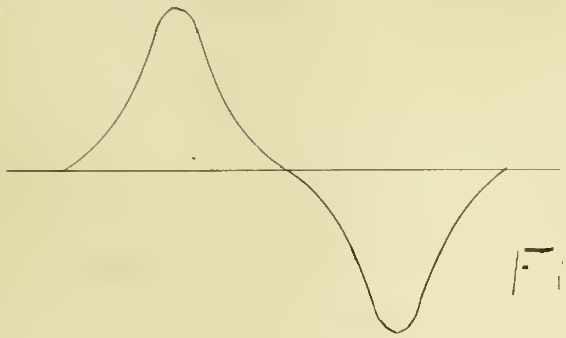


Fig. 1.

This is because the inductance has the effect of increasing the time-constant of the circuit and retards the flow of current in the first part of the wave and allowing it to rise very rapidly towards the 90 degree point. Such a curve as shown in figure 1, however, could only be obtained under the conditions of very low lagging power factor, (a very high inductance), and in general they would be more like figures 2 and 3.

Fig 2.

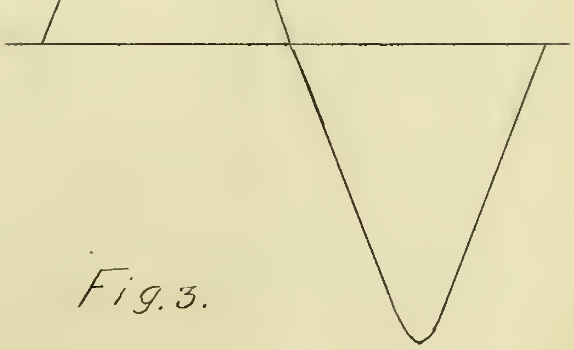


Fig. 3.

2. The effect of capacity in the circuit is exactly the reverse of that of inductance. The wave is flattened rather than peaked, showing that the harmonics are in the form of low frequency oscillations. Capacity effects are shown in figure 4, which shows also the way in which the sine wave harmonics combine to produce the deformed curve actually given by a circuit containing capacity. Figure 5 show the effect produced by excessive capacity. The condenser effect was produced by synchronous converters operated under the conditions of the so called "Gutmann experiment". (See thesis of A. C. Hobble. Phase Transformers.) This consists in sending a single phase alternating current into the armature of the machine from the commutator end and while the armature was rotated at or below synchronous speed, taking out one, two or three phase alternating currents from the collector rings, principally three phase being desired.

3. A curve showing this effect is given in figure 6a which shows the effect of combined capacity and inductance. The effect of a very low inductive power factor produced by the operation of a General Electric three phase induction motor, and operated in parallel with a synchronous motor, over excited, which produced a capacity effect, is evident in sudden drawing in of the curve immediately above and below the line of zero potential, while the serrated or saw tooth appearance of the wave at its peak shows the presence of the capacity. The effect on the same circuit, when a part

of the inductive load was removed, was to change the form to figure 6b. Here the drawing in of the curve is not so pronounced but the curve is of very sharp form, and the two small pointed peaks on the sides of the wave show that harmonics were present due to the capacity produced by the synchronous motor, and that the resultant wave of the circuit is made up of a great many higher frequency sine waves, combined with a smaller number of lower frequency curves. A combination of capacity and inductance in a circuit, tends merely to deform the wave due to either alone and not to produce a flattened nor peaked form. Neither does it seem that capacity tends to correct the deformation due to inductance.

4. The use of an electrolytic condenser, while producing conditions of leading currents similar to those of electrostatic capacity did not produce the deformation expected, but gave a wave of the same form as that due to inductance. This fact is significant, and it might be profitable to use an electrolytic condenser in a combination, as for instance, with a telephone line to overcome the deformation of wave form due line capacity. This remark is purely speculative, nothing of the kind being attempted and is not to be understood as referring to any efforts to produce neutralization in transmission lines. The fact, however as noted above, shows that in conducting experiments involving the construction of laboratory equiptment to produce artificial conditions of a long distance transmission line, it will not be proper to produce the line capacity by means of an electrolytic condenser, since the wave form distortion is not the same as that produced

under actual conditions.

5. The deformation of wave form obtained when operating the synchronous motor over excited, did not follow the law for electrostatic capacity, but gave a curve showing the combined characteristics of a variable reactance. This may possibly have been due to the fact that the circuit on which the synchronous motor was operating was already largely inductive.

6. The effect of the load on the wave form is evident, not in the flattened or peaked character of the curve but in its general shape. In general, a heavy load tends to make the curve lean over towards the right, while if the machine be working under conditions of light load or open circuit, the wave is more likely to be upright in position.

7. Pumping of a synchronous motor has the effect of so deforming the wave in a circuit as to give curves which are not symmetrical, that is, the lower and upper halves of the wave are not exactly similar, and succeeding waves may be slightly varying in form. When the pumping is very pronounced, this effect extends beyond the particular circuit on which the motor is operated, and may even react throughout the entire system of leads on the machine supplying the current.

8. The deformation of the wave form in any circuit is dependent not alone on the conditions in that particular circuit, but is affected by all the conditions imposed on the circuit by the machine. For instance, the plant supplied light from the 110 volt secondaries of the 440 volt system.

Power was taken direct from the primary, operating induction motors, and the laboratory was supplied from two sets of transformers. Any change in the reactance of any one of these circuits influences the whole system, changing the wave form in each of the other circuits. This was especially noticeable in the wave form taken from the secondary of the plant when the inductance in the primary was changed. The starting or stopping on an induction motor on the primary produced a change of wave in the secondary. This is probably due to the fact that the inductance throws lagging currents back upon the generator, producing large armature reactions, materially changing the distribution of flux in the pole tips.

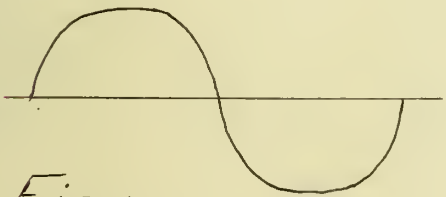


Fig. 4.

Fig. 5.

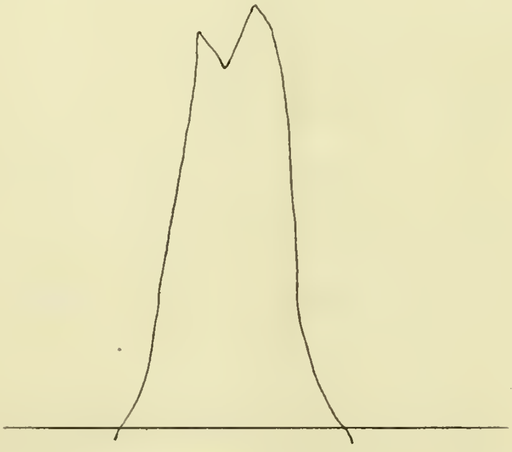


Fig. 6a

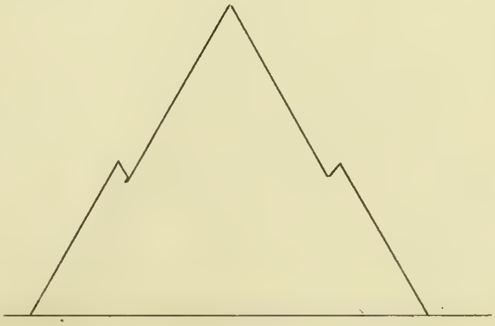


Fig. 6b.

Chapter V.

Modification of Existing Apparatus.

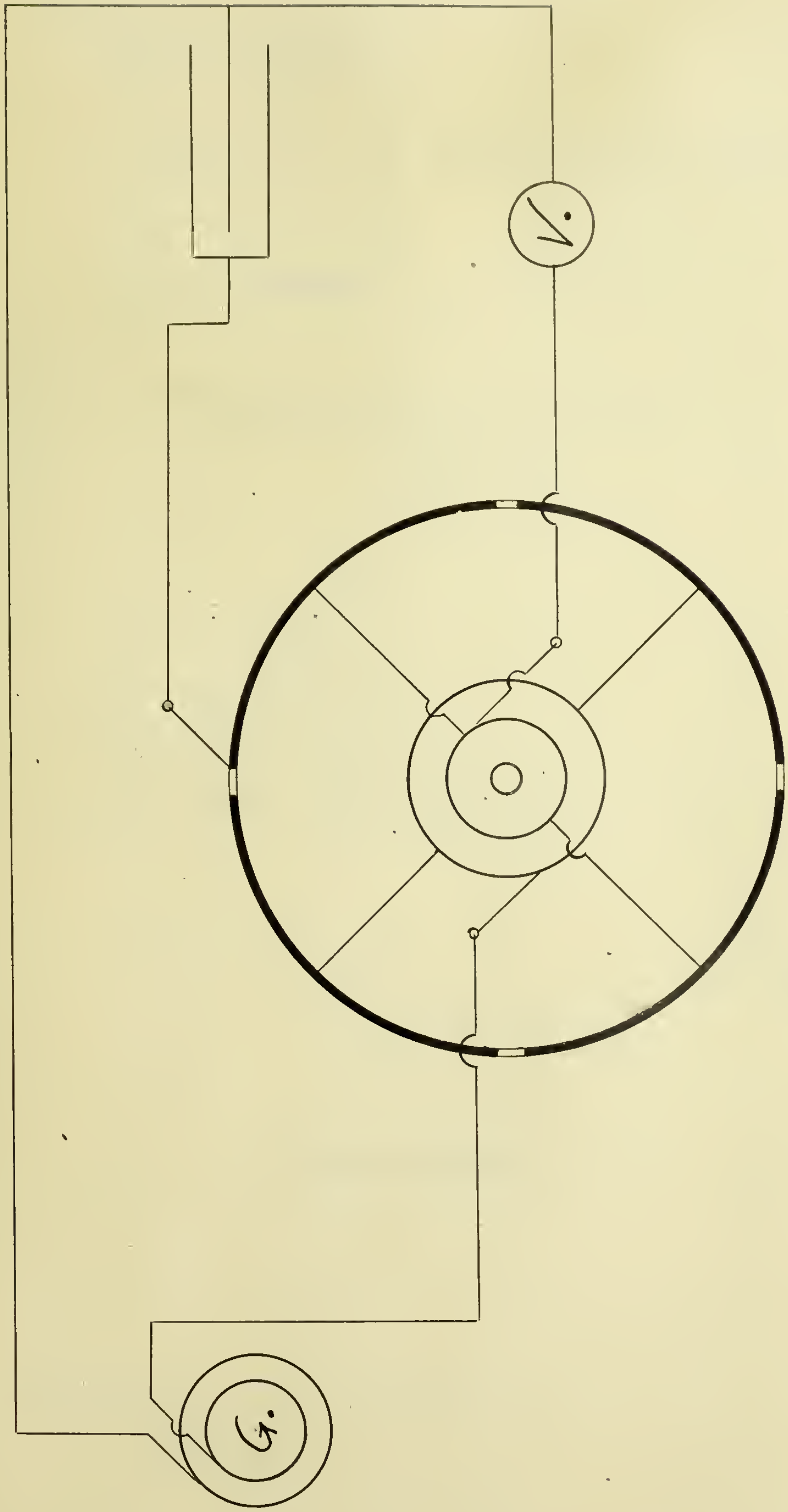
In conclusion, it might be well to point out some of the modifications and improvements which might easily be applied to instruments now in use.

The contact maker does not seem to be capable of very much modification for special work, nor for very much improvement as regards its general operation, it having reached what may be considered its most perfect form in the contact maker and condenser combination described in Chapter II.

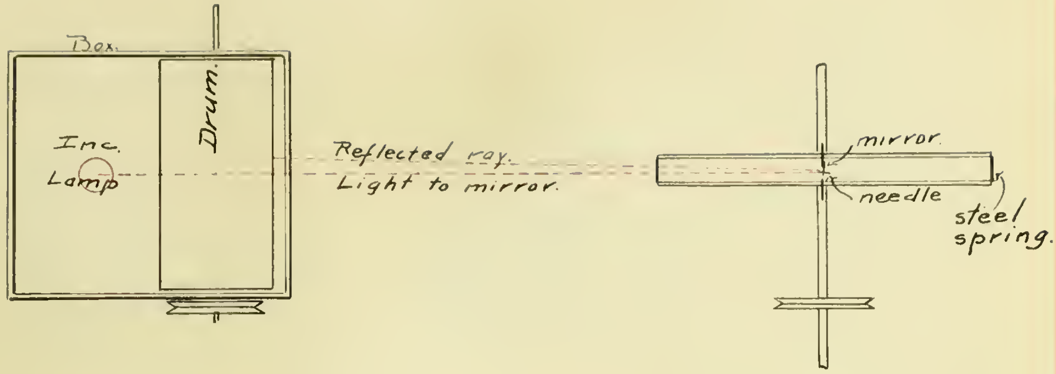
The curve tracer, however, as constructed by Mr. Carpenter is capable of several modifications. It is possible to construct it for either E.M.F. or current curves, or both. By the use of two wheels, one for current, and one for E.M.F. the phase relations could be shown on the bromide paper. If two current wheels should be used it would be possible to show the relative phase positions of the spring and secondary currents in the transformer. This however, would involve a special design of the windings of the magnets, adapting them for series work instead of being in shunt. It would also be possible to show the phase positions of two phase currents, and the addition of a third wheel would enable the same

investigations to be made for the three phase currents. This last is of some considerable importance, as it could be applied to the study of currents from the Scott two-phase, three-phase transformer, and to what has been called the " upset three phase", that is, the three phase currents derived from combinations of transformers, giving a modified form of three phase.

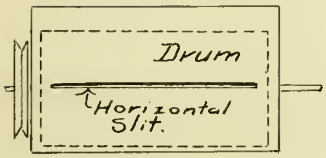
Of course the operation of the curve tracer would be made much more difficult by the reason of the greater number of parts to the mechanism and the addition of one or two curves, all of which would have to be adjusted to a common base line.



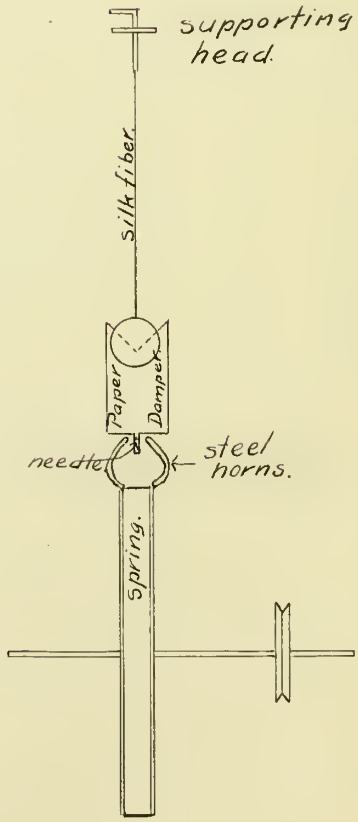
General Electric Co's. Contact-maker.
Plate I



Carpenter's Curve-tracer.
Plan view.



Box. Front view elevation.



Mognetometer.

Diagram of Curve-tracer.
Plate II.

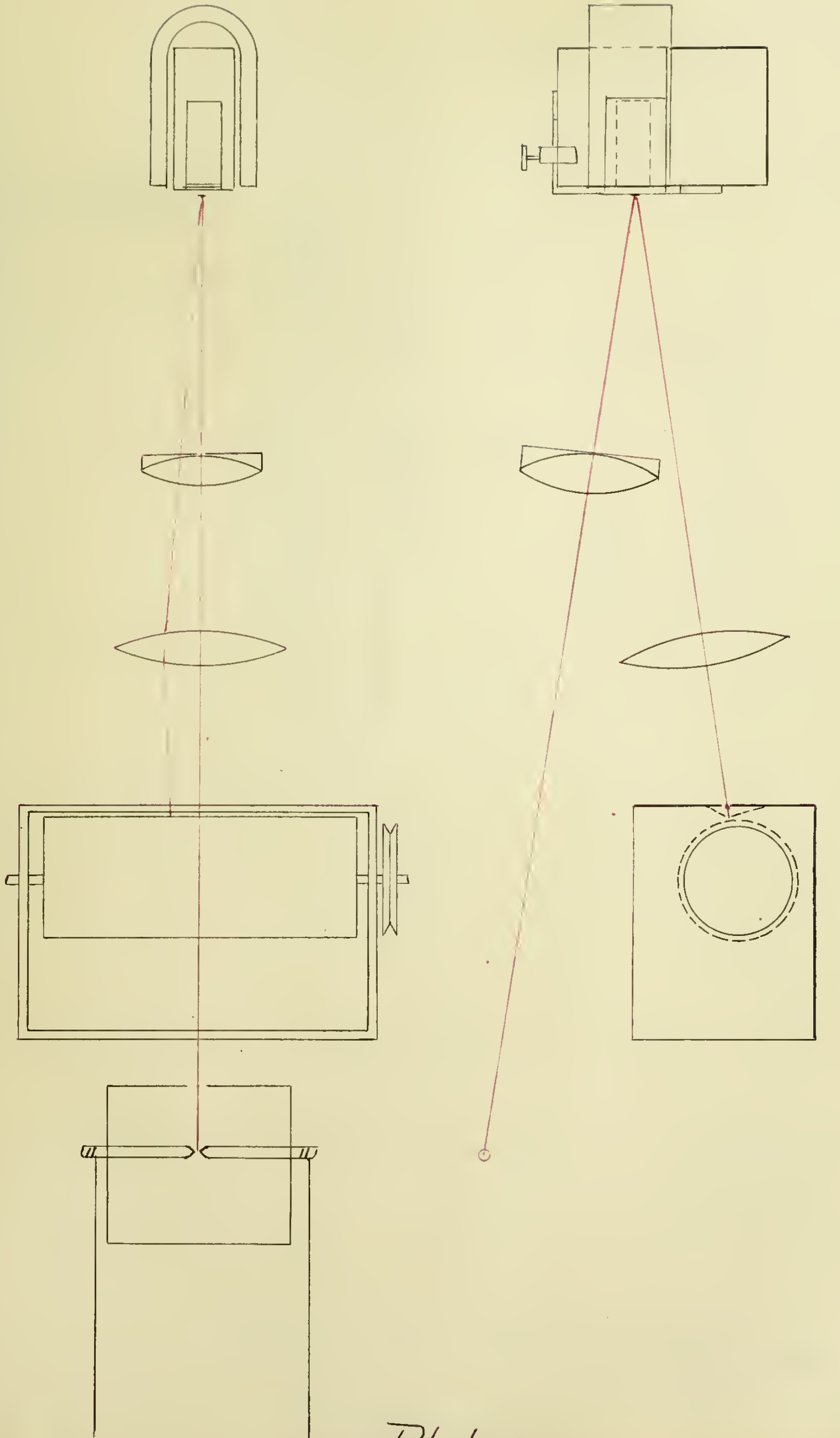


Diagram of Oscillograph.

Plate III.

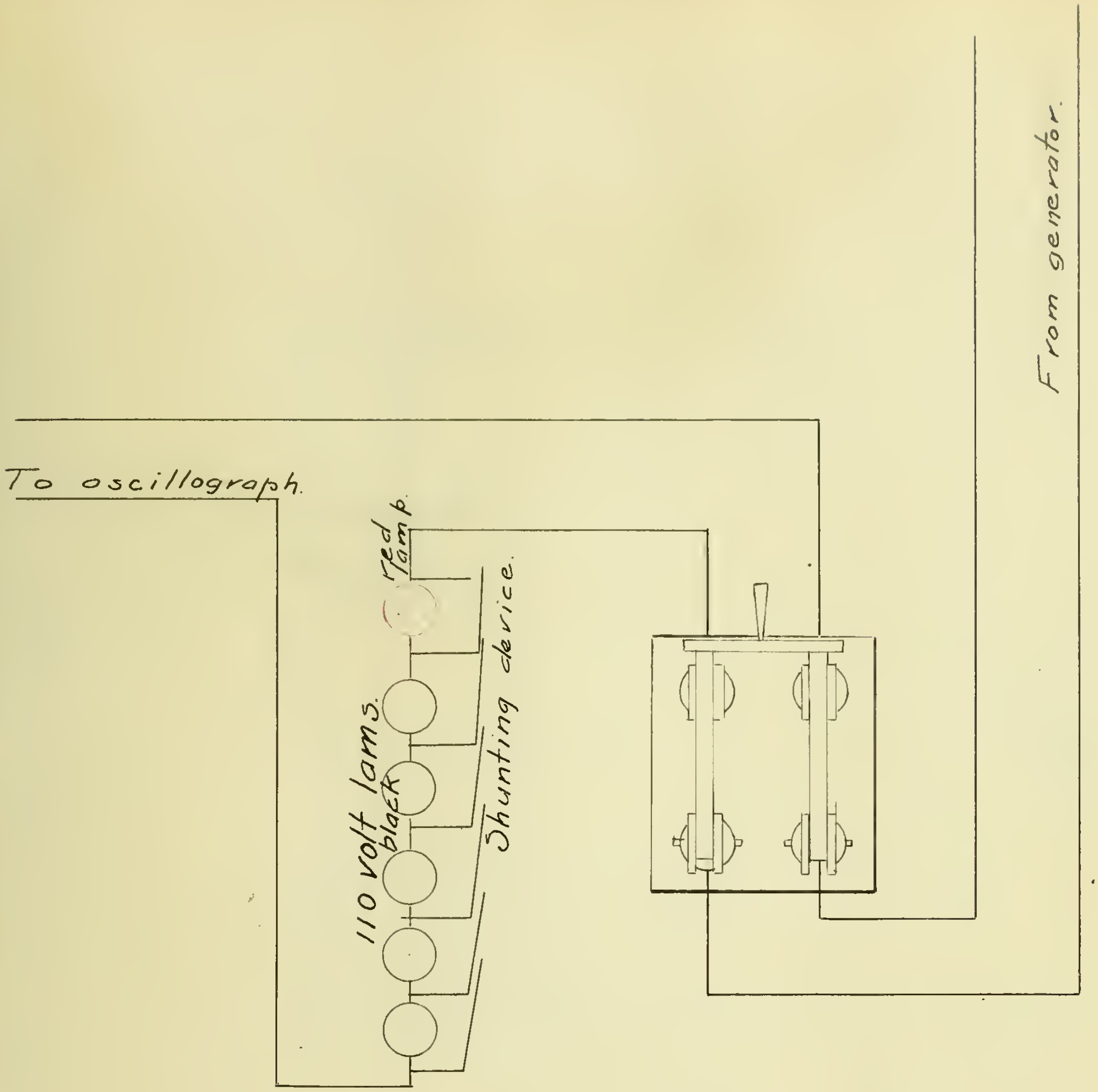
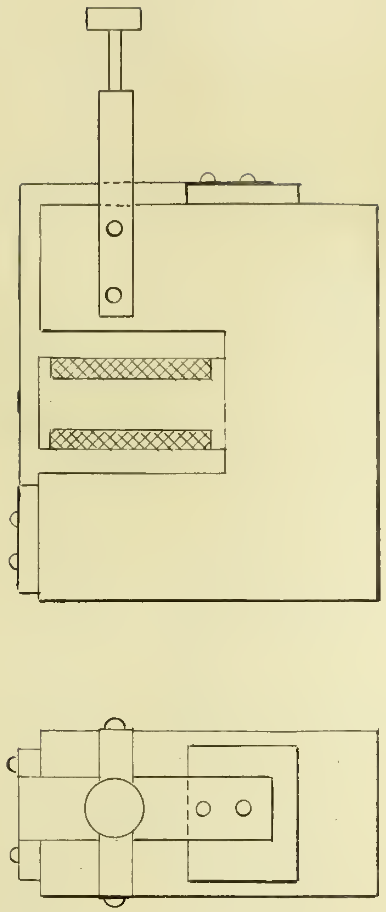


Diagram of Switchboards.

Plate IV.



Details of Galvanometer.

Plate V.

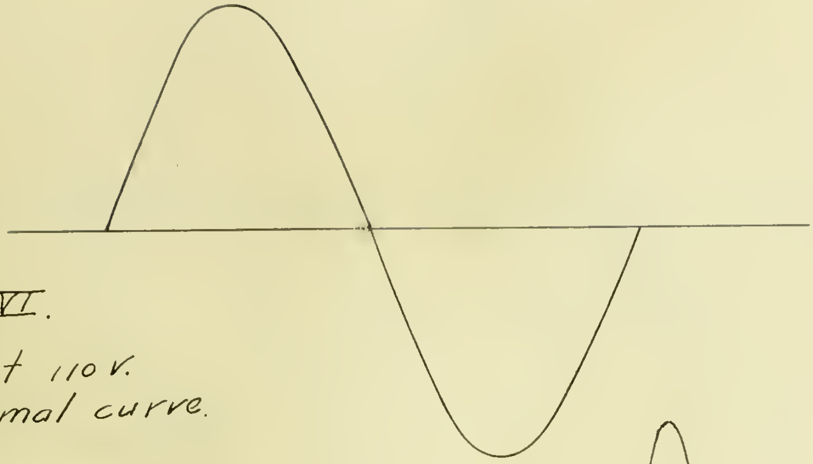


Plate VI.

Plant 110 v.
Normal curve.

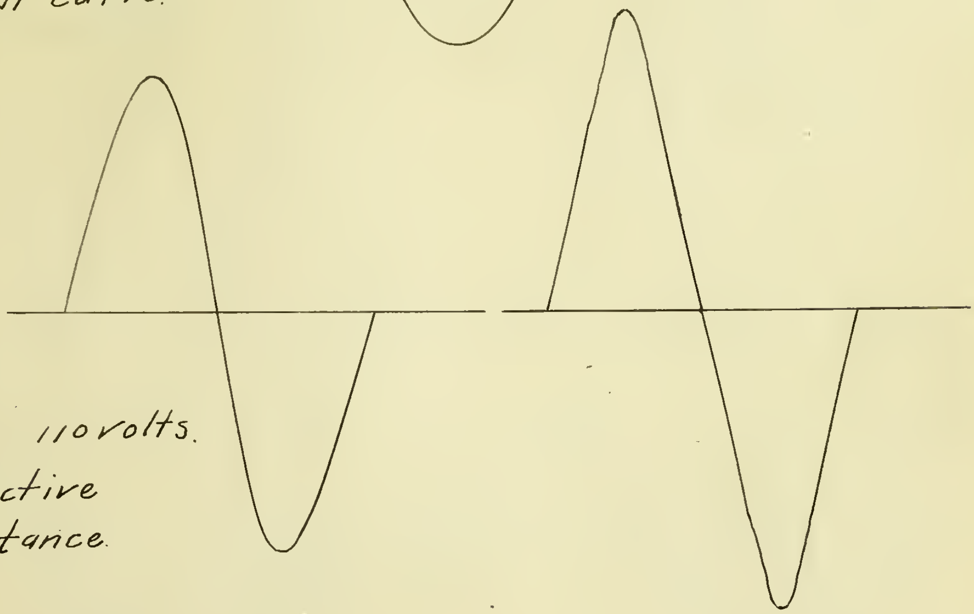


Plate VII.

Plant. 110 volts.
Inductive
Reactance.

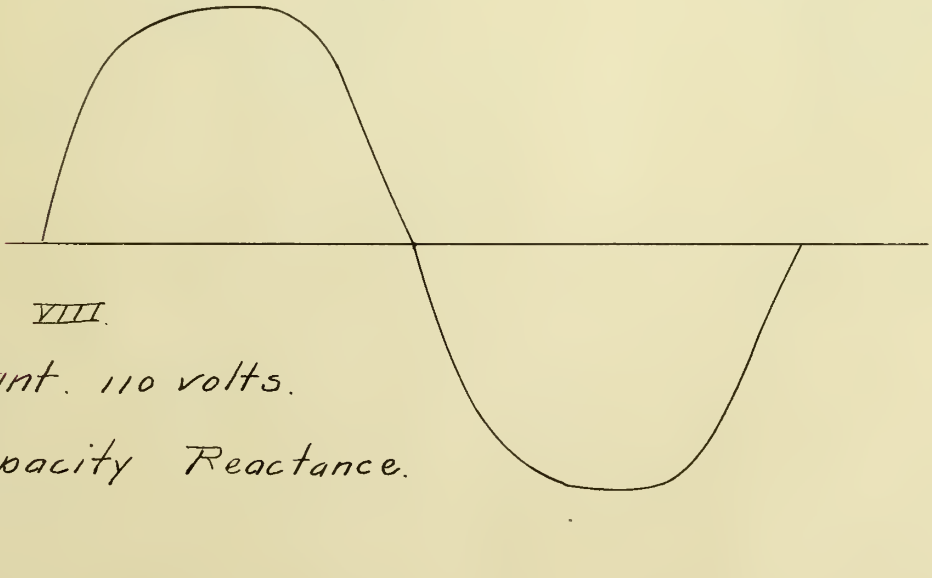


Plate. VIII.

Plant. 110 volts.

Capacity Reactance.

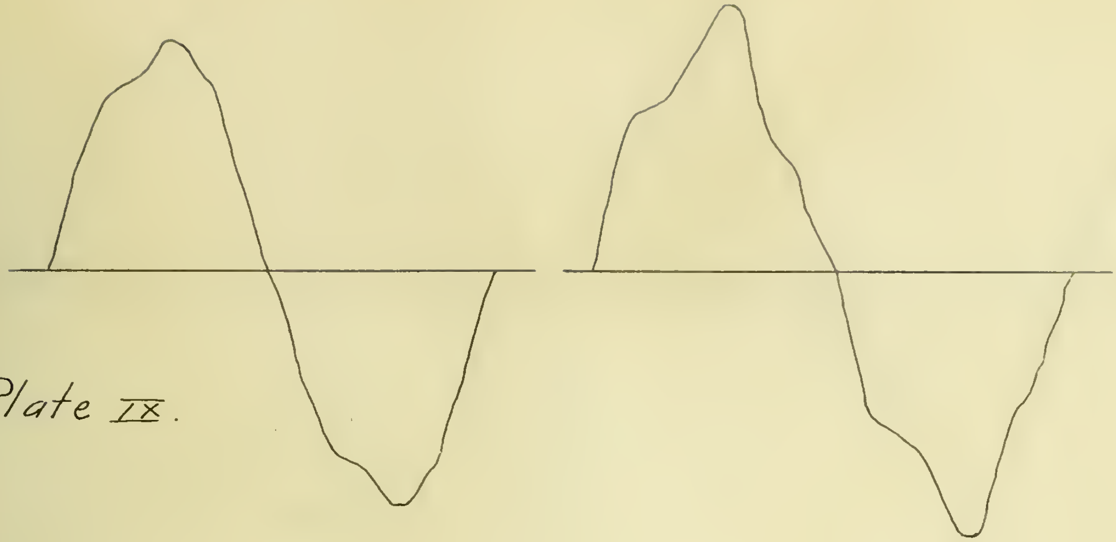


Plate IX.

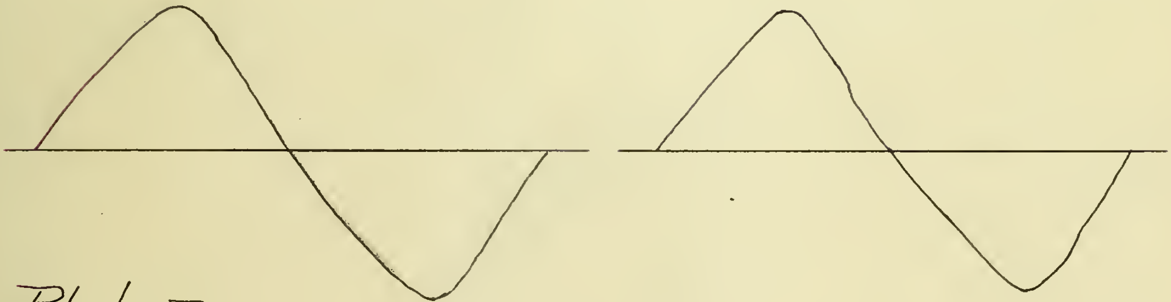


Plate X

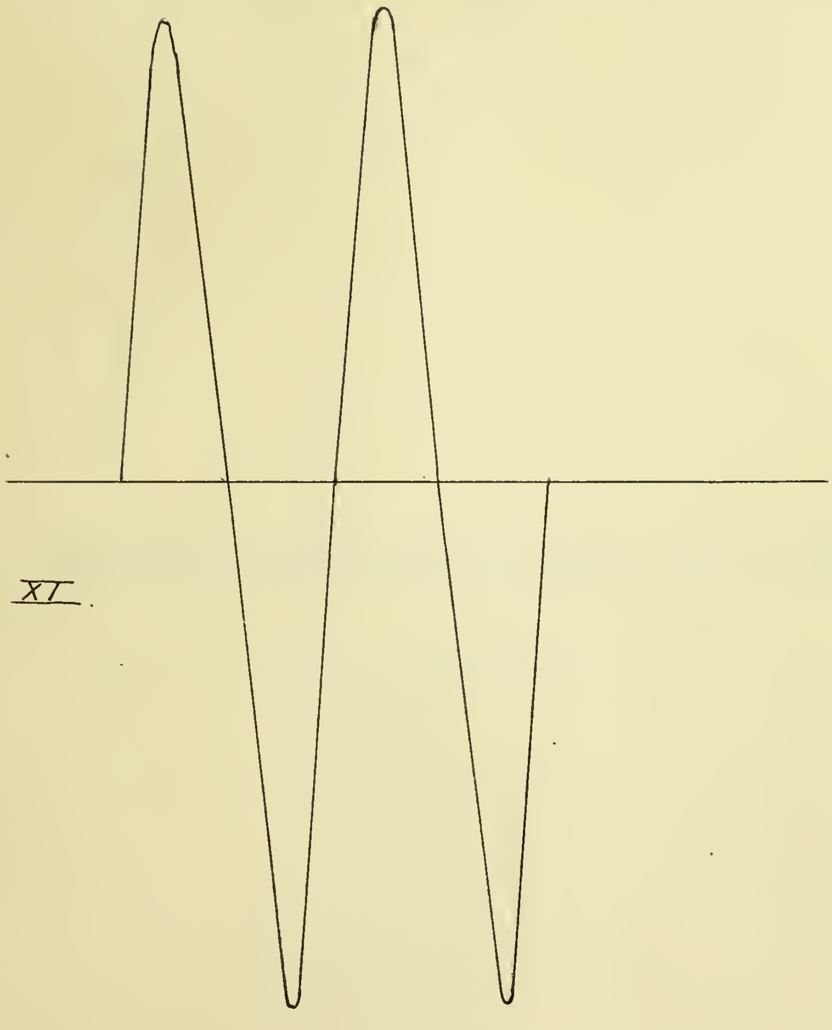
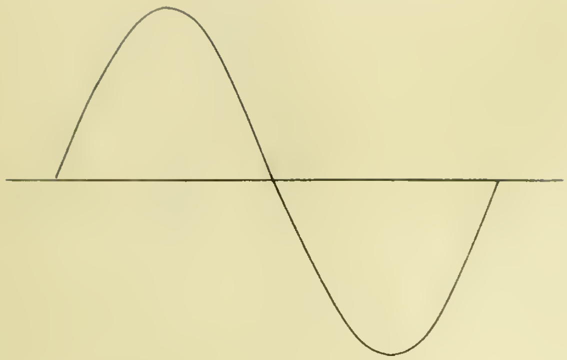
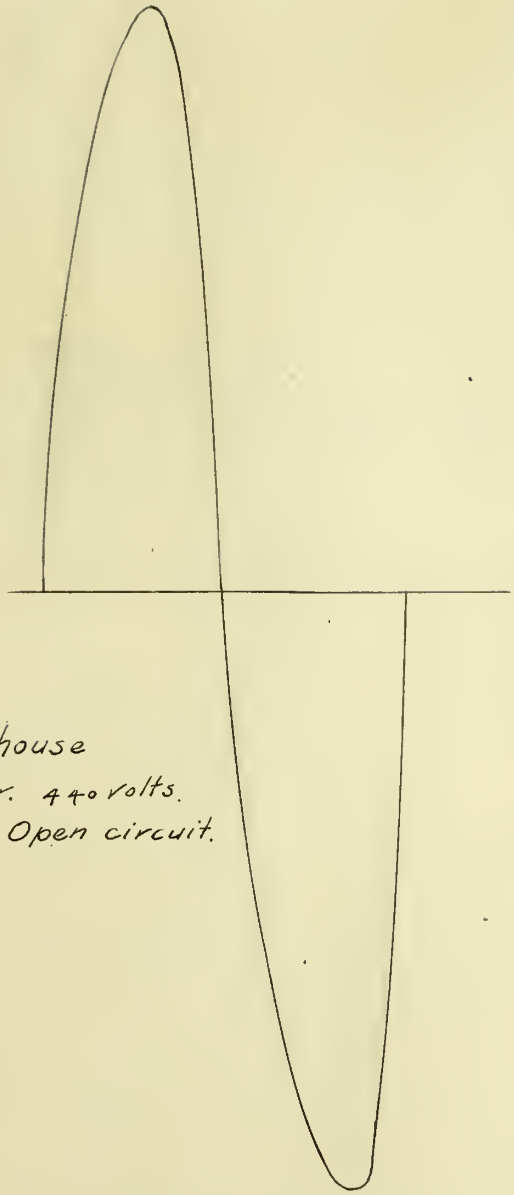


Plate XI.

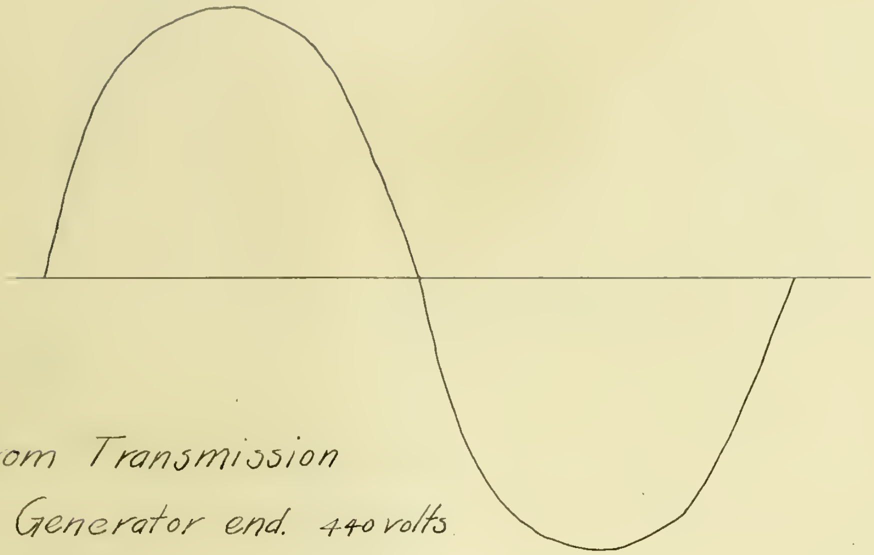


Westinghouse Converter. 440 volts.
Open Circuit.
XII.

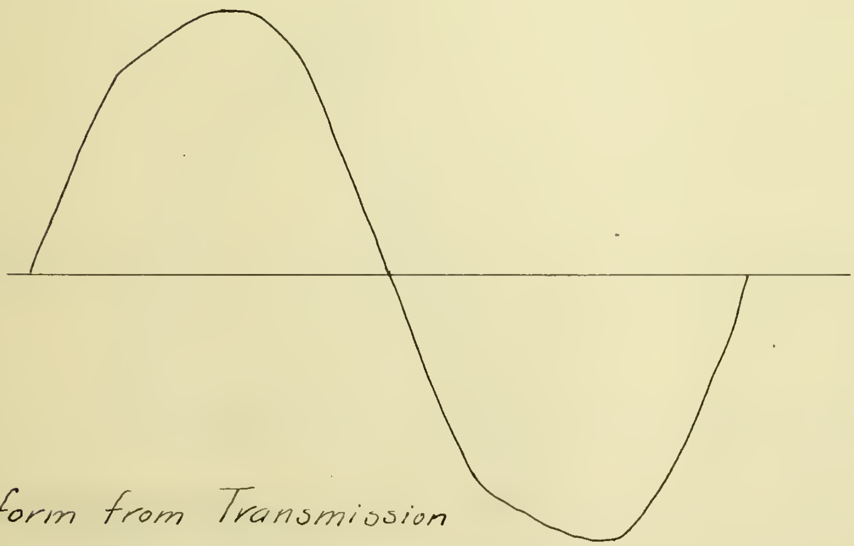


XIII.

Westinghouse
Converter. 440 volts.
3 phase   Open circuit.



Wave from Transmission
Line. Generator end. 440 volts
XIV.



Wave-form from Transmission
Line. Receiver end. 440 v.
XV.

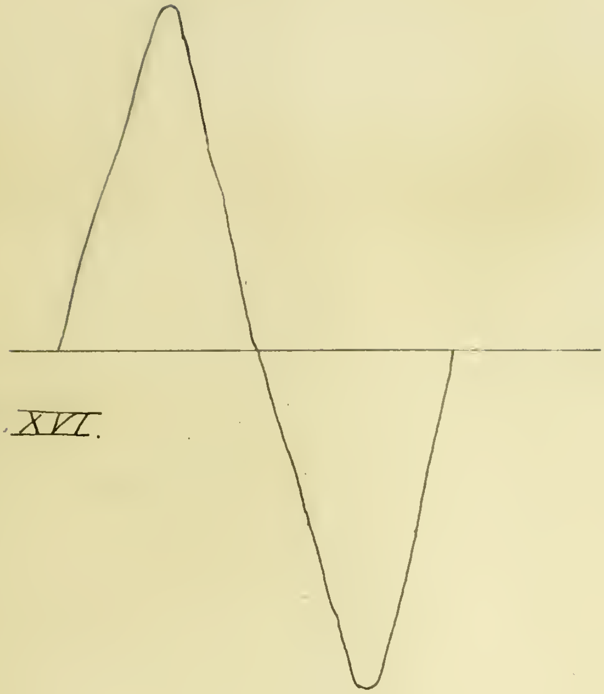


Plate XVI.

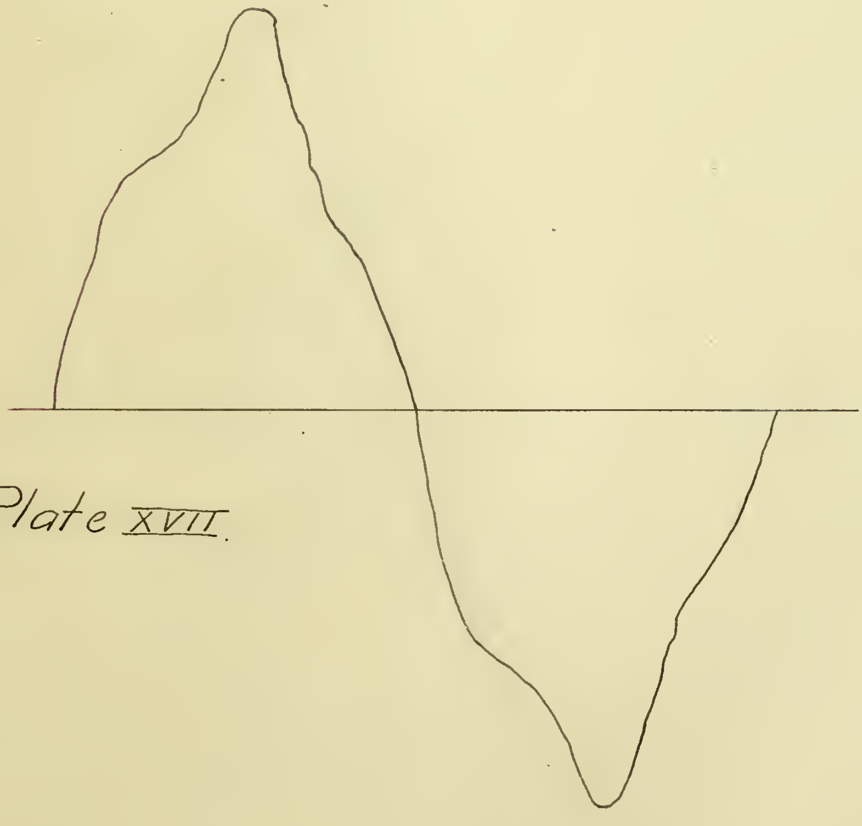


Plate XVII.